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FADING AND ERRORLESS TRANSFER IN SUCCESSIVE DISCRIMINATIONS[1]

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A successive discrimination between red positive and green negative stimuli was established with pigeon subjects. Then, lines with different angular orientations were superimposed on one of the colors to form compound stimuli. Finally, either the colored element of the positive compound, the colored element of the negative compound, or both colored elements together, were gradually attenuated. Before each attenuation, the line elements were presented alone against dark backgrounds as probes to assess the degree to which they had acquired control of responding. When the positive color was attenuated alone or in conjunction with the negative color, angular orientation acquired control of responding in an errorless fashion. Lines, however, did not acquire control when only the negative component was attenuated. These results were interpreted in terms of changes in the predictability of reinforcement by color and line elements during stimulus attenuation. Finally, attenuation of the negative stimulus influenced the number of "dimensions" of the new line stimuli that acquired control of responding. When the positive stimulus was attenuated with the negative, only one dimension of the lines acquired control. When the positive stimulus was attenuated without the negative, however, more than one dimension of the lines acquired control of responding. These results were interpreted in terms of how errorless performance can be maintained while an organism attends to different dimensions of the new stimuli.

Key words: fading, successive discrimination, multidimensional stimulus control, errorless transfer, predictability of reinforcement, probe stimuli, blocking, key peck, pigeon

New stimuli can acquire dimensional control of responding in an errorless fashion using a procedure called stimulus fading (Moore and Goldiamond, 1968; Schlosberg and Solomon, 1942; Sidman and Stoddard, 1967; Terrace, 1963). After establishing a discrimination between an original stimulus that occasions reinforcement, (S+), and an original stimulus that does not, (S−), new stimuli are superimposed on the original stimuli forming compound S+s and compound S−s. Thereafter, the original stimuli are gradually attenuated. During the course of attenuation, responding continues to occur in the presence of the compound S+ and rarely, if ever, occurs in the presence of the S−s. Finally, when the original stimuli are eliminated and the new stimuli are presented alone as S+ and S−, responding occurs predominantly to the new S+. While demonstrating that the new stimuli acquired dimensional control of responding in an errorless fashion, only Schusterman (1967), Touchette (1971), and Fields, Bruno, and Keller (1976) actually measured the point and the rate at which the new stimuli acquired control of responding. In addition, the extent to which attenuation of each of the original controlling stimuli influenced the acquisition has not been investigated. In the present experiment, probes consisting of the new S+ and S− presented alone were delivered before each attenuation of the original stimuli. Responding to the probes gave an estimate of the way attenuation of each original stimulus influenced acquisition of control by the new stimuli.

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METHOD

Subjects

Twelve experimentally naive White Carneaux pigeons, about 2-yr old at the beginning of the experiment, were maintained at approximately 80% of their free-feeding weights.

Apparatus

A Scientific Prototype pigeon chamber (Model No. B-400) was housed in a sound-attenuated enclosure. Visual stimuli were projected through the 25-mm diameter response key from an IEE In-Line display unit (Model No. 10-6777-44L). Stimuli consisted of the unilluminated key (dark), the key transilluminated with 630- (red) or 555- (green) nm light and white lines 3 mm wide and 25 mm long, with 0, 45, 90, or 135 degree angular orientations. Stimulus intensities were varied by changing the value of a resistor (Heath Decade Resistor, Model No. EU-30) wired in series with the display unit projector bulbs (Chicago Miniature No. 44, 6.3 V, 1.6 W). Response-key depression required a force exceeding 0.2 N. Reinforcement consisted of 3-sec access to mixed grain. During experimental sessions, white noise was present in the experimental chamber, and the chamber was illuminated with a 6-W houselight. Experimental contingencies were arranged with electromechanical logic modules.

Procedure

Preliminary training. After a subject was trained to peck a red key illuminated through a 0-ohms series resistance, where every response produced food, the number of responses required for reinforcement increased by two responses per session up to 30. For three to six sessions, responses at irregular intervals averaging 15 sec resulted in food presentation.

Establishing a red-green discrimination. A random series of full intensity red stimuli and green stimuli were presented. Each red stimulus (S+) lasted for an average of 15 sec and varied from 10 to 30 sec. Reinforcers were available during the last 5 sec of each S+. The S+ periods ended when a response produced the reinforcer, or after the 5-sec availability period if a response did not occur. Each green stimulus (S−) lasted 30 sec, during which responses had no consequences. Each S+ and S− period was followed by a 10-sec intertrial interval (ITI), during which the response key was black. Intertrial responses delayed onset of the next stimulus by 10 sec. All sessions lasted for 70 reinforcer presentations. Subjects were studied under these conditions until responding occurred only in S+.

Introduction and superimposition of new line stimuli. Red and green stimuli were presented at full intensity. Following every one or two presentations of the colored stimuli, one of two white lines was presented at full intensity against a black background for a duration ranging from 10 to 30 sec and averaging 15 sec. For two subjects, 0° and 90° lines were used. For the other two subjects, 135° and 45° lines were used. The two lines were presented in random order. Responses emitted in the presence of the lines had no scheduled consequences. Presentation of these line probes continued until neither evoked a response for five successive presentations.

Thereafter, the resistance in series with the bulbs projecting the lines was increased to 40 ohms, and each line was superimposed on one of the colors, forming compound stimuli. Thus, for example, red-horizontal was S+ and green-vertical was S−. Following every fourth S+ presentation, the resistance in series with the bulbs projecting the lines was decreased by 4 ohms until the compounds contained lines presented at full intensity. At that point, each full-intensity line against a black background was presented once under extinction conditions as a probe. Probes were presented following the third and fourth S+ for durations averaging 15 sec and ranging from 10 to 30 sec. The session was then ended.

Fading out the original controlling stimuli. Red-line compounds were presented as S+s and green-line compounds were presented as S−s. While the intensity of the line elements remained constant at 0-ohms resistance, the intensities of the colored elements were varied or remained constant, depending on the experimental conditions. Thus, either red and green were faded together, or red alone was faded, or green alone was faded. When the original S+ and S− elements were faded out together, the resistance in series with the bulbs projecting the red and green stimuli was increased simultaneously in 4-ohm steps following every fourth S+ presentation until probe responding began. Then, stimuli were attenuated in 2-ohm steps. When the original S+ element alone was faded out, the resistance in series with the bulb projecting the red element was increased as described above following every fourth S+ presentation, while the green S− element was always presented at full intensity. When the original S− element was faded out alone, the resistance in series with the bulb projecting the green S− element was increased as described above following every fourth S+ presentation; the red S+ element was always presented at full intensity.

For all conditions, before each increase in resistance, each line element was presented once at full intensity against a dark background under extinction conditions for a period lasting from 10 to 30 sec and averaging 15 sec. These probes were presented after the third and fourth S+. Subjects in all groups were studied until response rate evoked by the S+ probe equalled or exceeded 95% of the prevailing S+ rate and no responding was evoked by the S− probe, at two consecutive fading levels. If this criterion was not satisfied once a resistance of 60 ohms was reached, fading was discontinued. A pilot experiment indicated that 60 ohms was below threshold for these pigeons.

Of the four subjects assigned to each experimental condition, two were studied using 0° and 90° lines and the other two using 45° and 135° lines, (see Table 1, columns 1 and 2). Line orientations were assigned randomly to subjects in each group.

RESULTS

For subjects in all conditions, the lines did not evoke responding before or after being faded in, indicating that they did not acquire control of responding while being introduced. In addition, when the original stimulus element or elements were faded out, responding occurred only in the presence of the compounds S+s, at rates indicated in Table 1.

The left column of Figure 1 illustrates probe responding when the red and green elements were attenuated together. Initally, neither line probe evoked responding. As fading progressed, responding to the S+ probe increased, while little or no responding occurred in the presence of the S− probes. Thus, control of responding was acquired predominantly by the angular orientation of the lines.

The middle column of Figure 1 illustrates probe responding when only the red S+ element was attenuated. Initially, neither probe evoked responding. Then, responding began to occur in the presence of both probe stimuli. Finally, responding to the S+ probe continued to increase while responding to the S− probe declined to zero. Thus, while angular orientation acquired stimulus control, the pattern of acquisition differed from that observed when both original stimuli were attenuated.

The right column illustrates probe responding when only the green S− was attenuated. No responding occurred in the presence of either probe, even though the intensity of the green stimulus was reduced to a subthreshold level. Therefore, the new stimuli did not acquire any control of responding while the original S− element was being faded out.

DISCUSSION

New stimuli acquired control of responding during attenuation of either the original S+

Table 1

Response rates (responses per minute) to each compound S+ during attenuation of the original stimuli

(1) Stimuli Faded	(2) Bird No.	(3) Lines Used (degrees)	(4) Color Attenuation: Fading Levels (ohms) 0	2-4	6-8	10-12	14-16	18-20	22-24	26-28	30-32	34-36	38-40	42-44	46-48	50-52	54-56	58-60
S+/S−	25	0/90	183	211	207	189	130	211	169	188								
S+/S−	36	0/90	157	154	162	159	134	151	151	147								
S+/S−	10	45/135	147	109	87	76	100	112	111	103	84	100	44					
S+/S−	31	45/135	107	116	147	131	145	160	153	133	159	180	146	150	174			
S+	53	0/90	265	207	160	212	192	202	209	194	225	214	48					
S+	40	0/90	92	110	99	76	66	80	98	104	117	96	82					
S+	29	45/135	172	175	171	192	194	195	205	195	191	196	186	198	180			
S+	53	45/135	37	52	74	67	81	72	76	75	76	67	72	96	60	67		
S−	55	0/90	156	141	167	133	143	157	140	175	152	173	148	157	163	156	164	142
S−	50	0/90	119	79	53	73	64	79	92	83	83	64	85	102	77	101	129	118
S−	58	45/135	95	69	75	69	111	70	87	92	101	110	92	110	99	99	108	110
S−	59	45/135	233	113	115	190	190	195	197	195	198	193	173	232	168	156	201	118

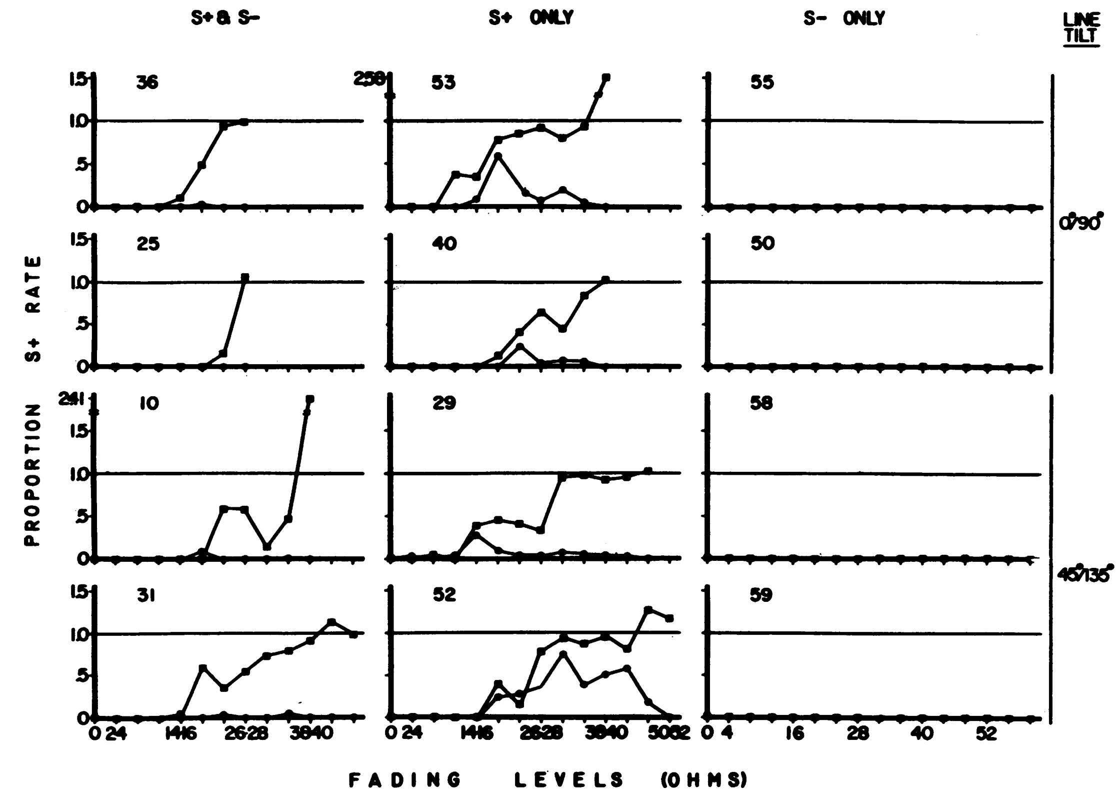

Fig. 1. Responding in the presence of the S+ and S— probes at each fading level. Each graph contains data obtained for an individual subject, identified by the number in the upper-left corner of each graph. The left column illustrates results obtained when the original S+ and S— were attenuated, the middle column illustrates results obtained when the original S+ alone was attenuated, and the right-hand column illustrates results obtained when the original S— alone was attenuated. The abscissa indicates fading levels measured in ohms where 0 ohms is full intensity and degree of stimulus attenuation is directly related to resistance level. Responding is presented as a proportion of the prevailing compound S+ response rate. Closed squares indicate S+ probe responding. Closed circles indicate S— probe responding.

and S— together or the original S+ alone. Attenuation of the S— alone, however, did not produce stimulus control by the line-tilt dimension. Thus, acquisition of control by new stimuli in fading was due to attenuation of the S+ only. These effects can be interpreted in terms of the effects of blocking (Kamin, 1968; Johnson, 1970; Miles, 1970; Vom Saal and Jenkins, 1970) and the predictability of reinforcement by the original and the new stimuli during the course of fading. Studies of stimulus validity (Wagner, 1969; Wagner, Logan, Haberlandt, and Price, 1968), concurrent chain schedules (Catania, 1966; Davison and Temple, 1974; Reynolds, 1963; Wardlaw and Davison, 1974), feature positive and feature negative effects (Wasserman and Anderson, 1975), and attention (Mackintosh, 1965; Maki and Leith, 1973) all suggest that control exerted by elements of compound stimuli is directly related to the extent to which the elements predict reinforcement. Since the stimuli in fading consist of compounds, the assumption was made that the control exerted by each element of the S+ compounds was proportional to their respective predictabilities of reinforcement. Predictability of reinforcement was estimated by computing the relative frequency with which reinforcement was made available for each S+ element under a number of representative conditions in fading. The assumptions made to estimate predictability of reinforcement were: (1) the availability of reinforcement during each S+ was assigned a relative frequency of 1.0, since one reinforcer was scheduled during each S+; (2) the availability of reinforcement during each S— and each ITI was assigned a relative frequency of 0.0, since no reinforcers were scheduled during those stimulus presentations; and (3)

S+s, S−s, and ITIs occurred in a ratio of 1:1:2 in the experiment, since one ITI followed every stimulus presentation.

Stimulus control before the attenuation of the original controlling stimuli. Before the attenuation of the original controlling stimuli, predictability of reinforcement by each element of the compound S+ was equal to 1.0. Thus, each S+ element should have controlled responding equally. Only the original S+ element (red) exerted stimulus control, however, because the S+ color, by virtue of its prior conditioning history, may be assumed to have blocked acquisition of control by the new S+ line element.

Stimulus control during the attenuation of the original controlling S+. Predictability of reinforcement may be computed for each S+ element as the stimuli along the original controlling dimension approach and become indistinguishable from the ITI. Changes in the predictability of reinforcement for the S+ element along the original controlling dimension may then be compared with equivalent values for the new S+ element under the same conditions. When the original S+ only is attenuated, in the limiting condition, it becomes indistinguishable from the dark ITI. Thus, one "dark" S+ would occur for every two dark ITIs, and the S+ element along the original controlling dimension would predict reinforcement with a relative frequency of 0.33. When the original controlling S+ and S− are attenuated, in the limiting condition, they both become indistinguishable from the dark ITIs. Thus, one "dark" S+ and one "dark" S− would occur for every two dark ITIs, and the S+ element along the original controlling dimension would predict reinforcement with a relative frequency of 0.25. Therefore, as the original stimuli were attenuated, predictability of reinforcement by the S+ element along the original controlling dimension would decline from 1.0 and approach limiting values of 0.25 or 0.33. In contrast, predictability of reinforcement by the new S+ element would remain at 1.0 throughout fading. As fading progressed, the new S+ element may be interpreted as having become a better predictor of reinforcement, having overcome the blocking effects of the original controlling stimuli, and having acquired control of responding.

Stimulus control during the attenuation of the original controlling S−. When the original S− alone was attenuated, the original S+ element did not change. Thus, it continued to predict reinforcement with a relative frequency of 1.0. Although the new S+ element also predicted reinforcement with an equal relative frequency, the original S+ element may be viewed as having continued to control responding and having blocked the acquisition of control by the new redundant S+ element.

To summarize, the development of control by new stimuli in fading may be interpreted in terms of stimulus blocking and the extent to which the elements of the compound stimuli predict reinforcement.

Dimensions of the new stimuli that acquire control of responding. Sidman and Stoddard (1976), Touchette (1968), and Fields, Bruno, and Keller (1976) have noted that many dimensions of the new stimuli in fading can acquire control of responding. In the present experiment, such dimensions of the new stimuli that acquire stimulus control may be tentatively identified in terms of the following assumptions: (1) S− probe responding reflects control exerted by a dimension that has the same value in each of the new stimulus elements, such as intensity or the central intersecting portion of each line; (2) the difference in S+ probe and S− probe responding reflects control exerted by the dimension differentiating the new stimulus elements, in this case, angular orientation.

When the original elements were attenuated together, the increase in S+ probe responding and simultaneous occurrence of minimal S− probe responding indicated acquisition of control by stimuli along the dimension differentiating the new S+ and S− elements, *i.e.,* angular orientation. When the original S+ element was attenuated alone, S+ and S− probe responding initially increased, after which S+ probe responding continued while S− probe responding dropped to zero. When both probes occasioned responding, control was exerted by (1) a dimension or dimensions having a common value in both new stimuli, such as line intensity or central locus of lines, and by (2) the dimension, angular orientation, differentiating the new stimuli. As fading progressed, angular orientation exerted increasingly predominant control.

In addition to supporting earlier observations that several dimensions of new stimuli in fading can acquire stimulus control, the present results suggest also that the number of such dimensions is determined by attenuation of the original S−. When attenuation of the original stimuli begins, control of responding can be acquired by different dimensions of the new stimuli. These dimensions are of two types: those that have different values in the S+ and the S− (angular orientation), and those that have the same value in the S+ and S− (intensity, for example). When only the S+ is attenuated, errorless performance can be maintained even though *both* dimensions of the new stimuli acquire control during S+ presentation, as long as behavior is under the control of color alone when the compound S−s are presented. Such a possibility is likely given the blocking properties of the full intensity S− color and the decremental blocking effect of the S+ color. As the intensity of the S+ color continues to decline, however, control acquired by both dimensions of the line increases until they begin to exert control during S− presentations. At that point, stimulus values along the two dimensions of the new lines begin to predict reinforcement differentially. Specifically, line tilts predict reinforcement with a higher probability than line intensity. Consequently, control exerted by line tilt begins to predominate. In contrast, when the original controlling S+s and S−s are attenuated concurrently, the blocking properties of both original stimuli decline together. As soon as lines begin to acquire control, responding probably will come under the control of line elements in both the S+s and the S−s. Thus, subjects will contact the different predictabilities of reinforcement associated with specific line tilts and intensity as soon as lines begin to exert stimulus control. The dimensional values that predict reinforcement with the higher probability (angular orientation) would therefore acquire predominant control of responding almost as soon as the new stimuli begin to acquire stimulus control.

REFERENCES

Catania, A. C. Concurrent operants. In W. K. Honig (Ed), *Operant Behavior: areas of research and application.* New York: Appleton-Century-Crofts, 1966. Pp. 213-270.

Davison, M. C. and Temple, W. Preference for fixed-internal terminal links in a three-key concurrent chain schedule. *Journal of the Experimental Analysis of Behavior,* 1974, **22,** 11-19.

Fields, L., Bruno, V., and Keller, K. The stages of acquisition in stimulus fading. *Journal of the Experimental Analysis of Behavior,* 1976, **26,** 295-300.

Johnson, D. F. Determiners of selective stimulus control in the pigeon. *Journal of Comparative and Physiological Psychology,* 1970, **70,** 298-307.

Kamin, L. J. "Attention-like" processes in classical conditioning. In M. R. Jones (Ed), *Miami symposium on the prediction of behavior: aversive stimulation.* Miami: University of Miami, 1968. Pp. 9-31.

Mackintosh, N. J. Selective attention in animal discrimination learning. *Psychological Bulletin,* 1965, **64,** 124-150.

Maki, W. S. and Leith, C. R. Shared attention in the pigeon. *Journal of the Experimental Analysis of Behavior,* 1973, **19,** 345-349.

Miles, C. G. Blocking the acquisition of control by an auditory stimulus with pretraining on brightness. *Psychonomic Science,* 1970, **19,** 133-134.

Moore, R. and Goldiamond, I. Errorless establishments of visual discrimination. *Journal of the Experimental Analysis of Behavior,* 1964, **7,** 269-272.

Reynolds, G. S. On some determinants of choice in pigeons. *Journal of the Experimental Analysis of Behavior,* 1963, **6,** 53-59.

Schlosberg, H. and Solomon, R. Latency of a response in a choice discrimination. *Journal of Experimental Psychology,* 1943, **33,** 22.39.

Schusterman, R. J. Attention shift and errorless reversal learning by the California Sea Lion. *Science,* 1967, **156,** 833-835.

Sidman, M. and Stoddard, L. T. The effectiveness of fading in programming a simultaneous form discrimination for retarded children. *Journal of the Experimental Analysis of Behavior,* 1967, **10,** 3-15.

Terrace, H. S. Errorless transfer of a discrimination across two continua. *Journal of the Experimental Analysis of Behavior,* 1963, **6,** 223-232.

Touchette, P. E. The effects of graduated stimulus change on the acquisition of a simple discrimination in severely retarded boys. *Journal of the Experimental Analysis of Behavior,* 1968, **11,** 39-48.

Touchette, P. E. Transfer of stimulus control: measuring the moment of transfer. *Journal of the Experimental Anlysis of Behavior,* 1971, **15,** 342-354.

Wagner, A. R. Stimulus validity and stimulus selection in associative learning. In N. J. Mackintosh and W. K. Honig (Eds), *Fundamental issues in associative learning.* Halifax: Dalhousie University Press, 1969. Pp. 90-122.

Wardlaw, G. R. and Davison, M. C. Preference for fixed-interval schedules: effects of initial link lengths. *Journal of the Experimental Analysis of Behavior,* 1974, **21,** 331-340.

Wasserman, E. A. and Anderson, P. Differential autoshaping to common and distinctive elements of positive and negative discriminative stimuli. *Journal of the Experimental Analysis of Behavior,* 1974, **22,** 491-497.

Vom Saal, W. and Jenkins, H. M. Blocking and the development of stimulus control. *Learning and Motivation,* 1970, **1,** 52-64.

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